UNCOOLED GaAlAs LASER ILLUMINATOR FOR NIGHT VISION APPLICATIONS

by

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Introduction

The use of supplemental radiation in night vision applications requires spectral matching to image intensifiers, high reliability and visual security. Semiconductor (electron injection) laser sources best satisfy these requirements because of wavelength selectivity and ease of operation.

Applications requiring high average radiant powers (~ 30 watts) are currently being satisfied with cryogenically cooled (77 K) GaAs (gallium arsenide) laser diode array sources. These systems suffer from large weight and size, as well as cooler noise.

A recent night vision application has required a light weight, man-portable laser spectrally matched to an S-25 type photocathode detector, but still offering visual security. This paper describes an experimental laser designed and fabricated to meet these requirements and a proposed improved design.

The specifications for the laser are shown in Table 1. The wavelength requirement of 850 nanometers eliminates all but two available semiconductor laser materials--GaAs cooled to 77 K and GaAlAs (gallium aluminum arsenide) with proper aluminum concentration. The cooling required for GaAs to emit at 850 nanometers would require a weight exceeding the two pound limit in addition to the logistic problem associated with liquid nitrogen. Therefore, GaAlAs was the only semiconductor laser material capable of meeting the performance and physical requirements. The final design is unique in that it is the first portable coherent GaAlAs illuminator operable at ambient temperature and not encumbered by the noise, weight and logistic problems associated with cryogenically cooled GaAs lasers.

General Description

The complete illuminator, as shown in Fig. 1, has a diameter of 4.1 inches and a length of 9 inches. The total weight, including housing, diode array, optics and electronics, is 1.91 pounds. The illuminator performance characteristics are given in Table 2. The most significant of the performance characteristics are the operating temperature of 300 K and the average

Fig. 1. GaAlAs laser illuminator.

Table 1. Performance requirements required of the laser.

Average power output	100 milliwatts
Radiation beam divergence	2°(H) x 1°(V) (rectangular)
Spectral emission wavelength	850 ± 10 nanometers
Pulse repetition frequency	650 hertz
Pulse width (maximum)	1 microsecond
Average power input	20 watts @ 24 VDC
Maximum weight (not including 24 VDC power supply)	2 pounds

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Table 2. Laser illuminator performance characteristics.

Average radiant power output	80 milliwatts
Peak radiant power output	410 watts
Spectral emission wavelength	850 nm ± 5.18 nm
Operational temperature	300 K
Output beam distribution	1.5°(H) x 1°(V) rect
Pulse repetition rate (effective)	1300 Hz
Pulse width (at half peak power)	150 nanoseconds
Input average power	15 watts @ 24 VDC
Power efficiency	0.53%

radiant power output of 80 milliwatts. Semiconductor laser illuminators have been fabricated to deliver output powers greater than the 80 milliwatts, but these required low temperature operation.

The system efficiency, the ratio of average radiant output power to average electrical input power, was 0.53%. The main factors contributing to this low value are the efficiencies of the electronics, the diode array, and the projection optics. These percent efficiencies are 57, 2.1 and 45, respectively. The total efficiency can be increased with improved arraying techniques and better optical collection efficiencies. A description of a fiber-optically coupled array offering lower electrical and thermal impedances and higher radiance and efficiency is given in a later section of this report.

The average power output of 80 milliwatts was realized by arraying 180 GaAlAs diodes and operating the array at an effective duty cycle of 1.95×10^{-4}. This duty cycle was accomplished by employing a double pulsing technique. With single pulsing, the operational duty cycle of the illuminator was limited to 9.75×10^{-5} by the requirement for synchronized operation with a gated image intensifier device operating at approximately 650 hertz and by a maximum pulse width of 150 nanoseconds set by the state-of-the-art GaAlAs diodes. The weight limitation for the illuminator would not permit arraying the required number of diodes to produce 100 milliwatts when operating at a duty cycle of 9.75×10^{-5}. By double pulsing the diodes every one microsecond gate of operation, the effective pulse repetition rate and the operational duty cycle were increased by a factor of two.

The illuminator diameter of 4.1 inches was dictated by the projection lens requirements of collecting the array power output being emitted in a full beam angle of 30 degrees and projecting the source output dimension of 0.250 inch into a beam angle of 2°. The total length was held to 9 inches by designing the pulsing electronics on four donut boards fitting around the diode array. A total illuminator weight of 1.91 pounds was realized by using a light weight plastic projection lens and by miniaturizing the pulse electronics through use of hybridized discrete-thick film technology.

An exploded view of the illuminator is shown in Fig. 2. This configuration provides light weight, small size and easy access to components for repair. The major components include the array, electronics and projection optics.

Gallium Aluminum Arsenide Diode Array

Designed into the illuminator was the desired feature of easy replacement of the diode array. This meant no soldered leads would be used to connect the array to pulsing circuits. As shown in Fig. 3, the array made electrical contact with the 20 pulsers through 20 copper contacts arranged in a circle around the array. The requirement for good physical contact between the copper terminals and the output of the pulsers was met by using a donut shaped pressure plate.

The array, Fig. 4, consisted of 10 subarrays, with each subarray containing 18 close-confinement, single heterostructure type GaAlAs laser diodes. The total number of diodes in the array was 180. Each subarray was electrically divided into 2 ports, with each port containing 9 series connected diodes. The subarrays were mounted in a stepped configuration resulting in a rectangular emitting area having dimensions of 0.250 inch by 0.250 inch. The array was mounted on a heat sink in a manner minimizing both weight and size.

The diodes of the array were electrically connected into 20 ports, with each port driven by 70 to 80 volts at a 40 ampere drive current. The two ports of each subarray had the p-layer of their center diodes connected to a common positive ground. The n-layers of the outer diodes of each port were connected to the negative side of individual pulsers.

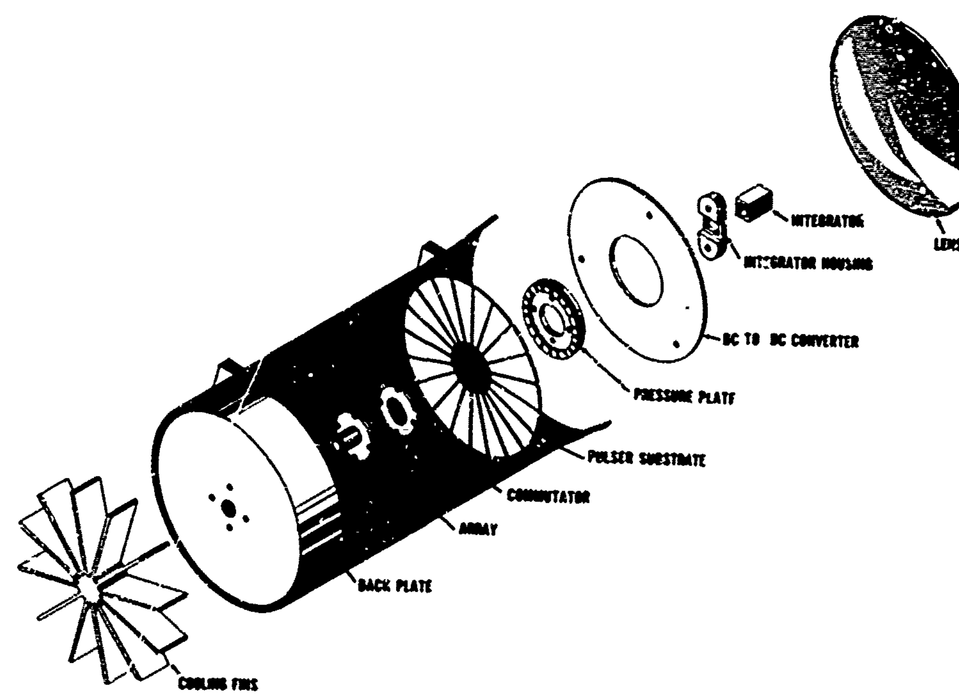

Fig. 2. GaAlAs laser illuminator (exploded view).

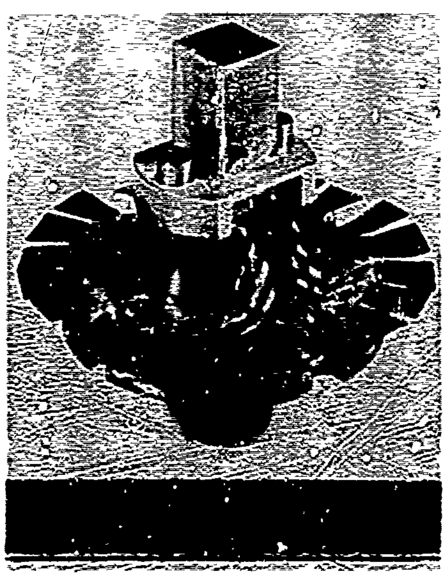

Fig. 3. GaAlAs laser diode array.

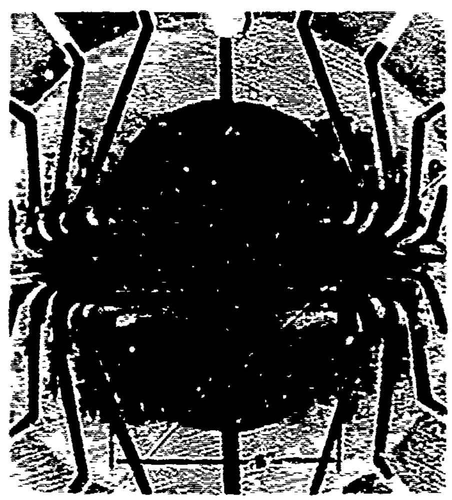

Fig. 4. GaAlAs diode array (top view).

The average radiant power output of the array was measured at 175 milliwatts. With each of the 20 ports being driven at approximately 65 volts and 35 amperes peak, the total peak input power to the array was 45 k watts. Operating at a duty cycle of 1.95 x 10^{-4} (pulse width of 150 nanoseconds and effective pulse repetition rate of 1300 Hz), the average input power to the array was 8.9 watts. Therefore, the array power conversion efficiency was calculated as 2.1%.

Pulsing Electronics

The total electronics package mounted to the housing end plate is shown in Fig. 5. This includes the 20 wedge-shaped laser diode drivers mounted to the end plate, and the DC-to-DC converter, generator and predrivers mounted on three donut-shaped shelves. The sole function of the electronics package was to provide current pulses to the array on command by an external signal originating in the gating electronics of the image intensifier system. The current pulses were approximately 35 amperes in amplitude and 150 nanoseconds wide at half peak power points. The voltage needed to develop this was from 60 to 80, depending upon the array impedance.

Table 3. Comparison of present and proposed GaAlAs laser illuminators.

	Present	Fiber-optic coupled
Semiconductor material	GaAlAs	GaAlAs
Wavelength (nanometers)	850 ± 2.5	850 ± 2.5
Operational temperature (°K)	300	300
Average power output (milliwatts)	80	250
Peak power output (watts)	410	1230
Number of diodes	180	150
Source emitting dimensions (inches)	0.250 x 0.200	0.080 x 0.040
Output beam divergence	2°(H) x 1.6°(V) (rect)	2°(H) X 1°(V) (rect)
Projection lens focal length	7.54	2.2
Projection lens F/num	1.9	1.1
Length (inches)	9	10
Diameter (inches)	4.1	2.1
Weight (pounds)	1.01	1.0
Power input (watts)	15 (0.6A @ 25 VDC)	11 (0.44A @ 25 VDC)

An improved design is proposed that incorporates newly available rectangular fiber optics for for coupling the radiation from the multiple laser diodes. This technique will result in a factor of 30 increase in the source radiance and will permit a significantly improved heat sink design. The proposed model, now in fabrication, will produce 250 milliwatts of radiant power in a 2 inch aperture system, will have an overall efficiency of 2.3% and will weigh only one pound.

Further improvements are forthcoming from additional improvements in the average efficiency of the diodes in the array as manufacturing yields are increased.

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While the outside package design was dictated by the optical requirements, the inside design was based on the need for short lead lengths to the array and the necessity of array maintainance. As stated, there are four shelves of electronics within this package. The uppermost shelf is the DC-to-DC converter and is shown in Fig. 5. An input of 24 volts results in a regulated output adjustable from 60 to 80 volts. This one board is heavier than the combined weight of the other electronics. It is also the most difficult to miniaturize because of the large number of transformers and inductors needed for high efficiency operation. The two center shelves contain the pulse generator (clock), Fig. 6, and the predrivers, Fig. 7. The pulse generator, on command from an external signal, generates two 150 nanosecond pulses within one microsecond for each command signal. The peak to peak separation of the pulses is approximately 750 nanoseconds. The double pulse is then shaped, amplified and multiplied to provide 20 separate outputs. These 20 signals are used to turn on the 20 switches simultaneously to operate the array. The switches are made in pie shaped wedges bonded to the back plate as shown in Fig. 7. This provides a good heat sink and common electrical ground to the array. This shape was chosen to better utilize the round configuration of the illuminator and to be in close proximity to the array to minimize inductance losses. This design lends itself to ease of maintainance of the array should it need replacing.

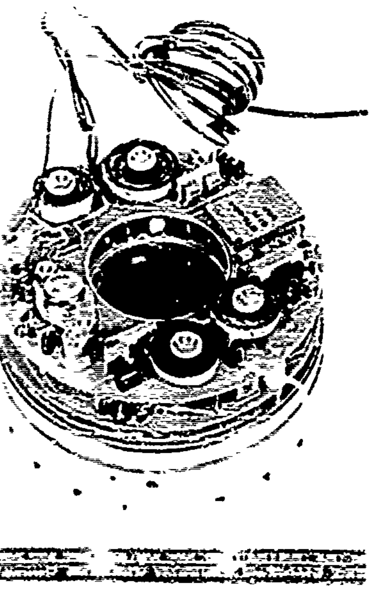

Fig. 5. Complete pulser electronics with DC-DC converter.

Projection Optics

The projection optics consisted of two components--a tapered hollow light pipe and a single light weight plastic lens. The plastic lens was thin film coated for 850 nanometers and had an optical transmission of approximately 93% at this wavelength. With an F/number of 1.9 and a focal length of 7.3 inches, the lens had a full angle collection of 30 degrees. The far field beam power distribution is shown in Fig. 8. The percentage of the total power falling within the 2 angular degrees of interest is 88%. This low percentage may be attributed to spherical aberration of the single lens, shortness of optical

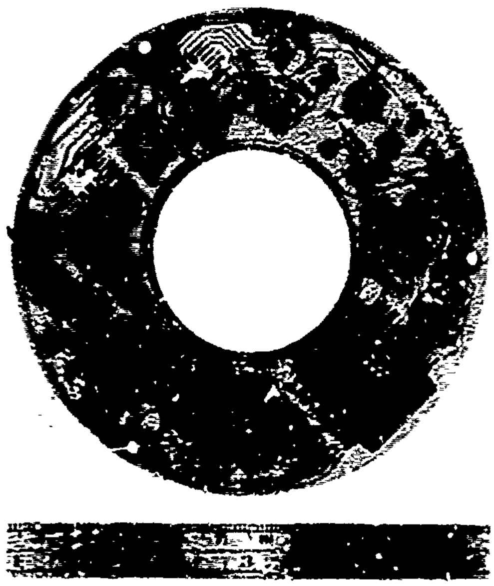

Fig. 6. Double pulse generator.

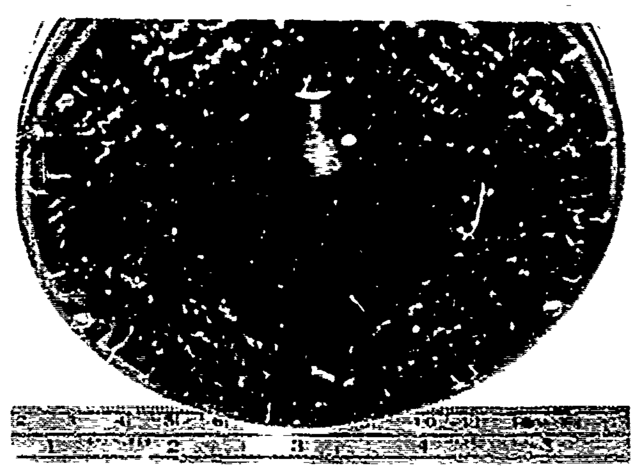

Fig. 7. Predrivor circuitry and wedge-shaped array pulsers.

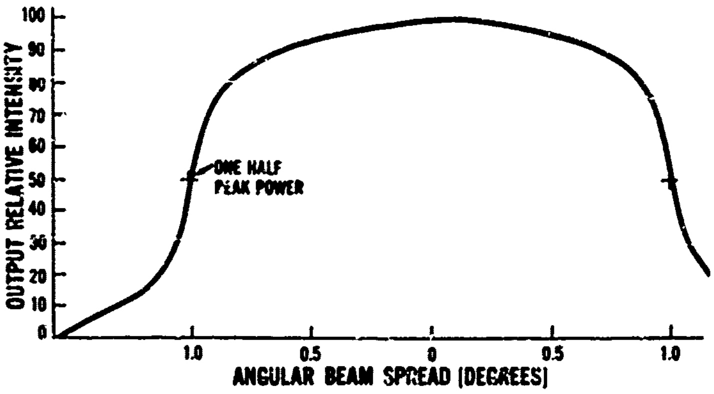

Fig. 8. Far field beam power distribution.

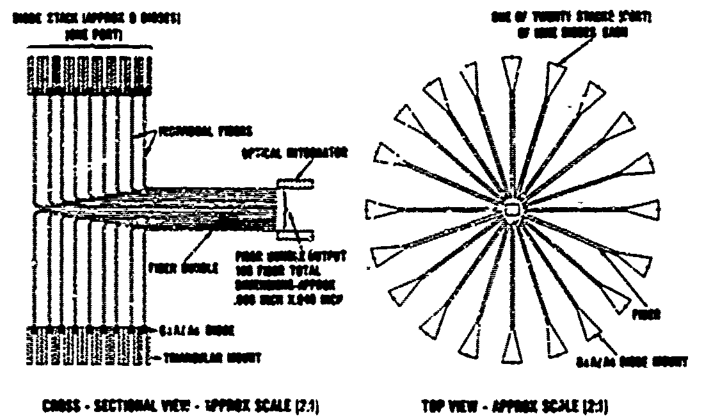

Fig. 9. Proposed fiber coupled GaAlAs diode array.

integrator producing insufficient scrambling of the light from individual diodes, and a lack of critical tolerances on dimensions of the integrator.

Improvements Offered by New Design

Although the present uncooled gallium aluminum arsenide illuminator has come close to meeting all the initial performance requirements, some night vision applications require lower weight, greater average radiant power output, and improved far field beam uniformity.

Illustrated in Fig. 9 is a new array design on which fabrication has been initiated. This design employs fiber optics coupled to GaAlAs diodes and terminated in a hollow pipe optical integrator. Benefits derived from using the fiber optics coupling technique are as follows:

1) a reduction in the total array electrical impedance by eliminating the small wire diode-to-diode electrical interconnects.
2) a reduction in the array thermal impedance (better heat dissipation) by eliminating the BeO electrical insulator required in the present array.
3) better diode heat sinking by allowing each diode to be mounted on individual heat sinks with greater spacing between diodes.
4) a reduction in pulser requirements--with better thermal properties, the present need for double pulsing (150 nanosecond pulse width) per gate to raise the duty cycle and the average power output is eliminated;
5) a reduction in source emitting area by a factor of approximately 15, resulting in increased radiance, and
6) a decrease in projection lens diameter by factor of two.

A quantitative listing of these benefits is given in Table 3. Most significant of these values are the average power output of 300 milliwatts, a reduction in both the number of diodes and the source emitting dimensions, a reduction in projection lens focal length from 7.54 inches to 2.2 inches, a reduction in illuminator weight from 1.91 pounds to 1.0 pounds, and a decrease in required input power from 15 watts to 11 watts.

Summary

A lightweight, man-portable semiconductor laser illuminator was described that represents the first application for arrayed GaAlAs laser diodes operating at 300 K. This prototype model clearly demonstrates the feasibility of radiation convection cooled illuminators producing radiant power outputs in the wavelength region of 850 nanometers to match the spectral sensitivity of S-25 image intensifier tubes. This illuminator emitting 80 milliwatts with an overall power efficiency of 0.53% weighs only 1.91 pounds.

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